PCM WALL ALTERNATIVES EQUIVALENT TO TRADITIONAL BUILDING SHELL IN HOT-DRY CLIMATE CONDITIONS

M. Kılınç[1], N.T. Bayraktar[2]
[1]Kocaeli University, Kocaeli, Turkey

ABSTRACT

Traditional settlements and buildings are great examples of architecture of a region with their original construction technics produced for adaptation to climate and topographic conditions as it is in dry climates with buildings with massive walls, the main architectural identity elements of this climate type. Massive walls store sensible heat, provide stable interior air temperatures and delay the peak temperature in the daytime. Furthermore, phase change materials that store the thermal energy in the environment as latent heat during solid-liquid, liquid-gas, solid-gas, and solid-solid phase changes and release the stored latent heat to the interior during reverse phase change can be used in dry climates constructed with thinner walls instead of old massive walls in newly built areas. PCM materials with thin layers can reduce heating, cooling loads and minimize interior temperature fluctuation as massive walls that can store sensible heat.

Within the scope of this study, wall alternatives with PCM material that offer similar performance to the internal operative temperatures provided by the building envelope with 90 cm typical thickness of outer walls of traditional buildings assumed to create ideal climatic conditions in Mardin, Turkey having hot-dry climate conditions are investigated for summer and winter conditions. Operative temperatures and cooling loads are obtained by simulation process conducted by Designbuilder energy analysis program.

INTRODUCTION

Energy demand is constantly increasing due to population growth, industrialization, technological developments, and changing lifestyles. It has disadvantages such as compensating the requirements with the limited amount of nonrenewable energy resources, increasing environmental degradation, and putting the sustainability of ecosystems at risk. The trends toward obtaining benefits from renewable energy sources in all sectors have gained importance today to reduce these negative effects. Similarly, it is possible that energy-efficient buildings integrated with the right strategies from the design stage with renewable energy sources, solar and wind to respond to different climatic and topographic constraints working as passive heating, cooling, air conditioning, and lighting systems to provide optimal interior climatic, visual comfort conditions without causing negative environmental effects.

Thermal energy storage systems, used for storing the energy to use when required, provide precious benefits in ensuring the continual use of renewable energy sources both daily and seasonally. Thermal energy storage is one of the methods used to meet energy needs such as heating and cooling. Thermal storage can occur in the form of sensible and latent heat storage (Konuklu and Paksoy, 2011).

Among the thermal energy storage methods, the latent heat storage method is one of the methods that has been emphasized in recent years and is frequently used to increase energy efficiency. Latent heat is the heat that a substance absorbs or gives off from the environment during phase change. This heat is stored by phase change materials. (Konuklu and Paksoy, 2011). When the material phase changes from solid to liquid it absorbs heat from the environment and it release heat when it solidifies. Phase change materials, classified as organic, inorganic, and eutectic according to their chemical components, store the thermal energy in the environment as latent heat during solid-liquid, liquid-gas, solid-gas, and solid-solid phase cycles, and release the stored latent heat to the interior during reverse phase change. Phase change material usage with dimensions much thinner than the material thicknesses used in sensible heat storage systems in buildings provide high performance of reduction of heating and cooling loads and minimization of temperature fluctuations.

During the phase changes, the operative temperature values in the environment remain stable in the phase change temperature ranges. The phase change temperature ranges of PCMs are selected among the options which provide acceptable indoor climatic comfort conditions. Thus, the thermal comfort of the occupants can be ensured by keeping the environment at stable temperature values. The type, thickness, surface area, and location of the phase change materials vary according to the climatic data of the region as investigated in the studies of Al-Yasiri and Szabó., 2021, and Bagazi et al., 2021.

Depe (2017) compared the effect of thickness variation of PCM material with different melting temperatures on thermal loads and internal operative temperatures in summer and winter climatic conditions for building envelope options in Diyarbakır, located in a hot climate zone in Turkey, and Erzurum in cold climate zone. The study determined that PCMs with high melting points in Diyarbakır under hot climate conditions, and with a low melting point for Erzurum, under cold climate conditions can be preferred (Depe, 2017). Therefore, it is necessary to increase the studies to evaluate the performance of PCM materials, widely used in the world, in different climatic conditions in Turkey for adaptation to local climate such as the building envelopes of traditional buildings with high thermal quality already providing optimal interior climatic conditions.

In regions with hot-dry climates, massive walls decelerate the heat gains in summer and the losses in winter by storing the excess heat for a specific time, reducing the indoor temperature fluctuations and creating stable desired temperature values. Massive walls, contributing to moderate interior microclimatic conditions by storing the sensible heat, are a significant issue of the urban identity, especially in traditional settlements like Mardin under dry climate conditions (Alioğlu E.F., 2000).

Mardin, located in the east of Turkey, is one of the candidates of the tentative list of UNESCO with its original city pattern formed by massive stone structures located on sloped topography concerning climatic parameters by opening up to the humid winds coming from the Mesopotamian plains located in the south of the region, and also getting benefit from desired amount of solar radiation in hottest and coldest period (URL1). Historical settlement orients 18º of South to SW on the ridges of the hills at a height of 950-1100 m with 20-25˚ inclination. Mardin has a compact urban pattern formed with narrow streets, courtyards and terraced structures on the slope, generating an original architectural identity for centuries.

The walls built with the chest wall technique that create the original character of the buildings in Mardin, the cradle of many civilizations with a history of at least 3000 years, make a capital contribution to the indoor microclimatic conditions today, as in the past. (Ok et al., 2014 and Manioğlu et al., 2008).

Figure 1. Traditional settlement views from Mardin

The inner and outer surfaces of the walls, with the chest wall construction technique in Mardin houses, were constructed using smooth cut or rough-hewn stone, and the middle wall layer is built with rubble stone. The height of the cut stones used varies between 0.21-0.25 meters. The wall thickness of the entrance floors built with these stones is between 0.8-2 meters, and the upper floors are between 0.75-0.90 meters. The thickness of non-load-bearing partition walls changes between 0.25- 0.65 meters (Alioğlu E.F., 2000).

However, traditional elements that contribute to the identity of old settlements and structures could not be sustained similarly in newly built areas as retention of old stonework technics of the craftsman were not transferred adequately to the present day. The requirement for new, high-rise buildings due to the increase in the city population by immigration created a tendency to reinforce concrete carcass structures. Stone is not used in new buildings as it is a heavy and expensive material (Figure 2.).

Figure 2. Reinforced building types in newly built areas in Mardin

Returning to the traditional construction techniques seems not to be probable in the short term, and this trend will continue in the long run. In this direction, the building envelope configuration with appropriate material layers in reinforced concrete and new building types in new settlements will at least offer the advantages of stone structures in these climatic conditions.

According to the definition in Turkey's national thermal insulation standard TS 825, the wall heat transmission coefficient for Mardin, located in the 2nd-degree day climate zone, is limited to 0.60 W/m^2K (TS 825). However, in this type of dry climate where massive walls are advantageous, it is necessary to use thicker insulation and wall materials compared to other climatic conditions to obtain optimal indoor operative temperatures in summer and winter with the effect of parameters, sensible heat storage, time delay, low heat transmission coefficient.

Walls with thin phase change materials having high heat storage capacity at smaller temperature ranges can be used instead of these new building envelope options with thermal insulation, which reach almost the thickness of the stone building envelope. Small amounts of PCMs can store high latent heat compared to other building components. They can provide a thermal mass effect without significantly increasing the weight of the building (Rincon, 2020). Rincon (2020) states that a 1.5 cm thick PCM has the same thermal storage capacity as a 9 cm concrete and 12 cm brick wall. The fact that walls with PCM provide similar performance to walls with thicker layers storing sensible heat will also offer an advantage of increasing occupancy areas in the spaces.

AIM OF THE STUDY

Massive walls used in traditional residential buildings in hot-dry climates store heat for a certain period, delaying the transmission by slowing down heat transfer and reducing the peak interior surface temperatures. With this effect, temperature fluctuations reduce. Occupants realize the indoor temperature values within the desired optimal value ranges. Today, chest-type stone walls, as the significant elements of the traditional building identity in dry climates, seem no longer to be a prevalent wall construction option due to the cost, expensiveness of the material, and the spread of high-rise structures due to the increasing population in newly built areas. With these preferences, the quality of the traditional building envelope in terms of improving thermal conditions and reducing unwanted thermal gains disappeared. Insulation materials with suitable thickness for hot-dry climatic conditions are adopted to achieve similar performance to traditional wall systems in new residential buildings. Utilization of alternative materials such as phase change materials with higher heat storage capacity in thinner forms in new settlements can also provide similar thermal quality to traditional building envelopes. The study aims to determine outer wall system alternatives with PCM, providing similar interior thermal conditions to traditional stone building envelope types in Mardin-Turkey under dry climate conditions. The performance of wall systems with PCM types selected due to temperature ranges within the indoor climatic comfort temperatures was investigated in terms of presenting similar or converging interior operative temperatures to the results obtained by the alternative with a traditional chest-type stone wall.

METHOD

The performance of the building envelopes generated with 3 types of PCM were investigated in terms of comparing the similarity level of the alternatives to internal operative temperatures provided by the building envelope with 90 cm typical thickness of outer walls of traditional buildings in Mardin, Turkey with hot-dry climate conditions is conducted by simulation process. The PCM materials are assumed to be applied to all inner surfaces of the building. The study used a square-shaped zone with 10*10*3.5 m dimensions at an imaginary building and compact settlement with characteristics of traditional Mardin residential buildings and urban patterns (Figure 3). PCM types have to be selected separately for the buildings in a district as the amount of sun and wind exposures and the shading effects differ for each. Therefore, the settlement of the building on sloped topography and the shading effects of other buildings are considered. Furthermore, night ventilation which is a common strategy in hot dry climates is assumed to be active in summer conditions. The effects of architectural elements for shading such as “Eyvan”, and “Revak” are ignored in the study.

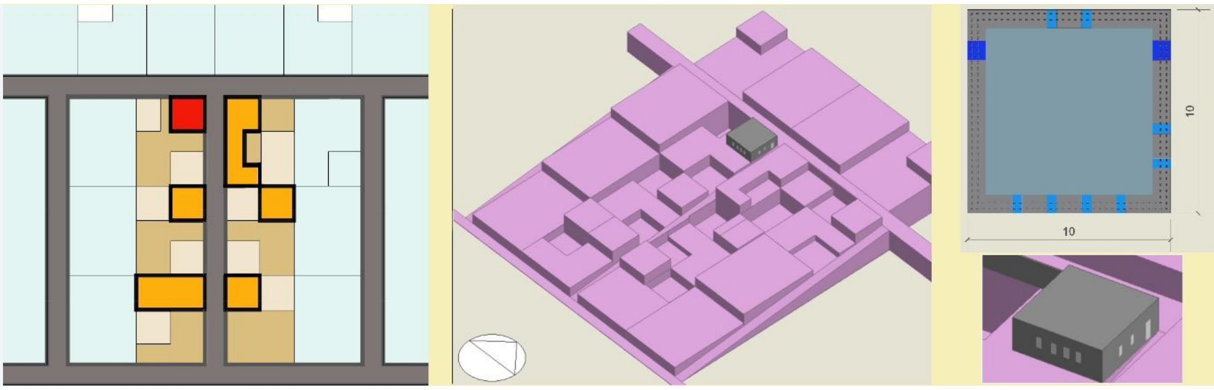

Figure 3. Building Model

Operative temperatures obtained by the wall alternatives with different PCM types are calculated by “Designbuilder” in order to make comparison with the alternative representing traditional stone wall referred as base model with 90 cm thickness. The changes in the indoor operative temperature values during the day were determined for all alternative conditions on January 1 and July 1 design days, when the heating and cooling systems were not operating. However, the heating and cooling systems are assumed to be active during the reference days for the heating and cooling load calculations. Conduction Finite Difference (CondFD) algorithm with consideration of the heat capacity of the material with the temperature-enthalpy function and delicate for assessment of PCM performance is used for the calculations with “Designbuilder” (Energyplus engineering reference 2022).

EnergyPlus IWEC files derived for Mardin province is used as climatic data The convergence of operative temperature values of the alternatives to the ideal alternative, [A-90-Stone-ref] with 90 cm thickness, representing traditional wall system in summer and winter design day conditions is investigated. Alternatives providing more similar conditions in terms of hourly operative temperatures in design days are determined. Interior operative temperatures and heating cooling loads that occur with and without PCM alternatives are compared with the conditions created by reference alternative.

Reference traditional wall and outer wall alternatives with 20 and 50 cm thickness, assumed to be generated by 3 types and properties of ‘BioPCM® M182 materials with different melting points are presented on Table 1. and Table 2. PCM materials are integrated on the inner surface of the outer walls for all the alternatives. BioPCM™ is selected as it is eco-friendly materials also harmless or nontoxic during fire (Beltran et al., 2017).

Table 1. Propeties of PCM alternatives (Designbuilder, 2009)

Thermal Bulk Properties	Units	<u>BioPCM Properties</u>
Conductivity	W/MK	0,2
Specific Heat	J/KGK	1970
Density	KG/M^3	235
Melting Temperature	oC	20
Freezing Temperature	^{O}C	23
Pcm Thickness	M	0,0742

Table 2. Wall Alternatives (Designbuilder Database)

		Layers	d (m)	λ (W/mK)	U value (W/m^2K)	PCM Location
1	**A90-Stone-ref**	Stone-tufa	0,25	0,35		inner
		Stone	0,4	1		
		Stone-tufa	0,25	0,35	**0,54**	
2	**B20-PCM23 B20-PCM25 B20-PCM27**	Perlite plastering	0,025	0,08		inner
		Biopcm	0,0742	0,2		
		Aerated concrete	0,085	0,11		
		Perlite plastering	0,025	0,08	**0,56**	
3	**C50-PCM23 C50-PCM25 C50-PCM27**	Gypsum plastering	0,015	0,4		inner
		Biopcm	0,0742	0,2		
		Aerated concrete	0,4	0,11		
		Gypsum plastering	0,015	0,4	**0,24**	

PCMs with 23°C, 25°C, and 27°C melting temperatures in accordance with thermal comfort temperature ranges suggested for buildings are selected. Figure 4 presents the temperature-enthalpy graphic of the PCM options.

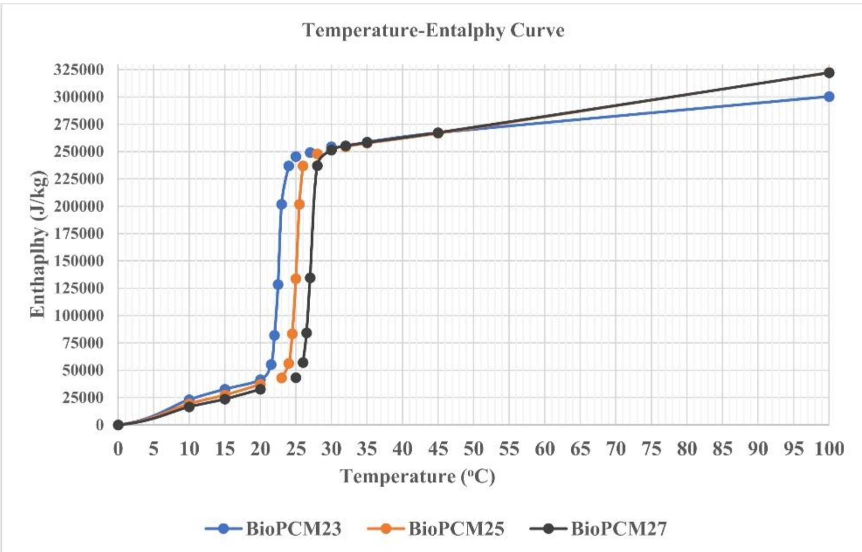

Figure 4. Temperature-enthalpy graphic of the PCM options (Designbuilder Database)

<u>RESULTS</u>

The variation of the indoor operative temperature values and heating cooling loads during the day were determined for all alternative conditions on January 1 and July 1 design days (Figure5). The outside temperatures vary between 19.5-30.5 ˚C at 07.00-16.00 on July 1 and between -3.0- 3.6 ˚C at the same time intervals on January 1, according to simulation data results for Mardin. The thermal loads and operative temperatures occurring in the reference days of summer and winter periods were obtained with the alternative stone wall configuration, which stands out as an architectural element that reflects the identity of the city and is considered the reference situation in the study. In the summer, operative temperatures with reference alternative, [A-90-Stone-ref] vary between 01:00 and 08:00 at high temperatures between 24.59 -24.89˚ C. It rises to 26.06-26.89 ˚C range between 09:00-16:00. It varies between 17:00-24:00 in the temperature range of 24.97-27.27˚C. In winter, with the same reference configuration, indoor operative temperatures are between 6.77-7.01˚C between 01:00 and 08:00. Temperatures rise to the range of 7.16 -7.59˚C between 09:00-16:00. Between 17:00-24:00, it changes to the temperature range of 6.57-7.56 ˚C. The maximum and minimum thermal comfort temperature range, stated as 23.5-26.6 ˚C in ASHRAE Standard 55-1992 for the 1.2 met, 0.5 clo conditions is exceeded with very low amounts among 13:00-18:00 in the summer period with the reference situation. Manioğlu 2008 measured operative temperatures with little deviations as around 24 ˚C, at traditional "Mungan" and 26 ˚C, at "Demir" houses in Mardin. Therefore, operative temperatures obtained by the alternative [A-90-Stone-ref] are similar to the measured data for summer conditions (Manioğlu, G., & Yılmaz, Z. 2008). This shows that the operative temperature data obtained by reference alternative is appropriate to present similar climatic conditions in Mardin. Furthermore, the Turkish National standard, "TS 825 Thermal insulation requirements for buildings" mentions the minimum temperature to be provided indoors as 19 ˚C for residential buildings. ASHRAE Standard 55-1992 suggests operative temperatures among 19.5 -23 ˚C with 1.2 met, 1 clo conditions. In their study, Bekleyen 2014 calculated operative temperatures among 8-10 ˚C in upper and lower rooms of a traditional house in Mardin. The measured data shows similarity with the daily operative temperature values obtained in the study for winter conditions (Bekleyen A., etc. 2014). However, daily operative temperatures measured and calculated both do not reach comfortable temperature ranges in winter conditions.

When the other alternatives formed with different types of PCM materials in alternate wall thicknesses are examined, it is observed that all alternatives create higher operative temperature values that are close to each other during 06:00-19:00 time interval compared to the reference situation [A-90-Stone-ref] in the summer period except the alternative [C50 -PCM25]. Operative temperatures of all alternatives with PCM decrease below reference alternative between the hours 19:00-24:00 providing comfortable climatic conditions. Temperature fluctuations with all alternatives are very low at all time periods. Operative temperatures with all alternatives are over outside temperature at all hours except 13:00-17:00. [C50 -PCM23] and [C50-PCM27] create the most similar conditions with the reference state, [A-90-Stone-ref] after the alternative [C50 -PCM25] at 09:00-18:00. The alternatives [B20-PCM27] and [B20-PCM23] caused more uncomfortable conditions than other PCM alternatives with operative temperatures between 28.9-26.72˚C during the day. The values nearest to the comfort temperature range were reached with [C50 -PCM25] for all hours for summer conditions.

The alternatives [C50-PCM23], [C50 -PCM25], [C50-PCM27] created higher operative temperatures ranging from 8.08-8.99 ˚C compared to [A-90-Stone-ref] in winter at all time periods. The highest operative temperatures are obtained with [C-50-PCM23]. [B-20-PCM23], [B-20-PCM25], and [B-20-PCM27] alternatives provided lower operative temperatures with values varying between 6.06-6.94˚C compared to [A-90-Stone-ref] at all time periods. The values closest to the comfort temperature range were reached with [C50 -PCM25], [C50-PCM27] after [C-50-PCM23] for all hours for winter conditions.

Sensible heating and cooling rates were calculated with the conditions when the heating and cooling systems were operating on the 1 January and 1 July design days. The peak sensible cooling rates occurred at 15:00 in the summer period. The maximum sensible cooling rate reached to 2.59 kWh with [B20-PCM23] at 15:00. The lowest values are obtained by the reference status, [A-90-Stone-ref] at all time periods. [C50-PCM27] provides the closest and the lowest sensible cooling rates to the reference state after [C50-PCM25] for all hours after 05:00, until 18:00.

The peak sensible heating rates occurred between 01:00-08:00 at 06:00 on the reference day in the winter period. The reference state seems to create higher sensible heating rate than [C50-PCM23], [C50-PCM25], and [C50-PCM27] at all time intervals. [C50-PCM25], and [C50-PCM27] provided the lowest heating rates while the options [B20-PCM23], [B20-PCM25], and [B20-PCM27] generated the highest sensible heating rates with very close values among all alternatives including [A-90-Stone-ref] for winter conditions.

Massive walls, the main characteristics of hot climatic conditions, are beneficial in creating a more moderate microclimate in the interior and obtaining stable indoor temperatures by reducing the external high-temperature values and delaying the effect on the interior surfaces. Based on the Mardin IWEC climate data, the simulation results obtained for July 1, representing the summer period, showed higher internal operative temperatures than the external temperatures in all periods except the hours 13:00-17:00 in summer conditions.

It is observed that low amount of temperature oscillations occur during the day both in summer and winter conditions. Simulations conducted also without natural ventilation caused high level of indoor operative temperatures reaching over 40 ˚C for all wall configurations including massive wall. This shows the importance of night ventilation in buildings with massive walls as a common strategy implemented in dry climates. Therefore, in the study, the night ventilation strategy was applied and, the windows were assumed to be open at evening hours.

Acceptible operative temperatures in summer period can be explained by the behaviour of the PCM materials during solid- liquid form among melting (23, 25, 27 ˚C) and freezing (20 ˚C) temperatures. During phase change latent heat storage increases without temperature rise by sensible heat.

Latent heat storage capacity of the phase-change material, which is constantly in solid form at low temperatures decreases in winter. 20 cm wall alternatives with PCM generated lower operative temperatures compared to [A-90-Stone-ref]. The alternatives [C50-PCM23], [C50-PCM25], and [C50-PCM27] provided higher operative temperatures and lower sensible heating rates as their sensible heat release capacity is high with 50 cm wall thickness. Temperatures are among 4- 6.9 ˚C. Although the contribution of latent heat by PCM is low compared to thick walls releasing sensible heat, higher operative temperatures occurred in the zone compared to, [A-90-Stone-ref]. This temperature increase is provided by the effect of PCM alternatives.

CONCLUSION

In the context of the study performance of wall types with PCM material in hot-dry climate conditions is investigated in terms of similarity of interior operative temperatures and heating cooling load variations to the conditions created by wall configuration with chest stone, a traditional construction contributing to optimal indoor comfort conditions in buildings in Mardin-Turkey. Massive wall types create temperate and stable microclimatic conditions in the interior with time lag, decrement factor, and low heat transmittance. Night cooling ventilation strategy also must be integrated to cool the building envelope and interior ambient environment to benefit from the low outside air temperatures at night.

In the study, the reference configuration with stone walls provided similar results with the measured data obtained from the literature. Wall types with PCMs selected due to melting and freezing temperature values within the recommended indoor climatic comfort temperature range presented similar performance in terms of providing low interior operative temperature and cooling loads as [A-90-Stone-ref] at all time periods with small temperature oscillations in summer. In winter period the contribution of PCM materials decreased as temperature variations of all alternatives were not among PCM melting and freezing temperature ranges. The contribution of PCM materials increased with combination of thicker walls.

All alternatives with PCM generated higher operative temperatures, heating, and cooling loads compared to the reference configuration on design day of summer. This occurred the same for winter conditions except for the alternatives, [C50-PCM27], [C50-PCM23], [C50-PCM25]. All PCM materials are in the solid phase with low latent heat storage and release in winter condition. Therefore, higher interior temperature variations compared to conditions with 20 cm thick walls are mostly caused by sensible heat from 50 cm walls.

[C50-PCM25] provides the lowest cooling loads in summer and winter conditions. [B20-PCM27] and [B20-PCM25] create a lower interior operative temperature than all the other alternatives with 20 cm wall thicknesses as they have the low enthalpy among 15-20˚C temperatures. However even these 2 alternatives show similar or converging interior operative temperatures to the results obtained by traditional chest-type stone walls alternative at all time periods.

Therefore [C50-PCM25], [C50-PCM27], [C50-PCM23] seems to be appropriate alternatives to adapt to dry climate conditions by providing lower temperatures in summer and higher temperatures in winter like reference wall configuration, [A-90-Stone-ref]. The performance of PCM materials with high melting and lower freezing temperatures on thinner walls also has to be investigated with also the integration of a night cooling ventilation strategy as suggested for the configuration with a stone wall.

Also, the selected zone for the simulation is at the highest location on the slope under low shading effects. Therefore, the shading effects of the other buildings in the district on energy consumption and thermal comfort performance may be investigated for the zones located at lower elevations.

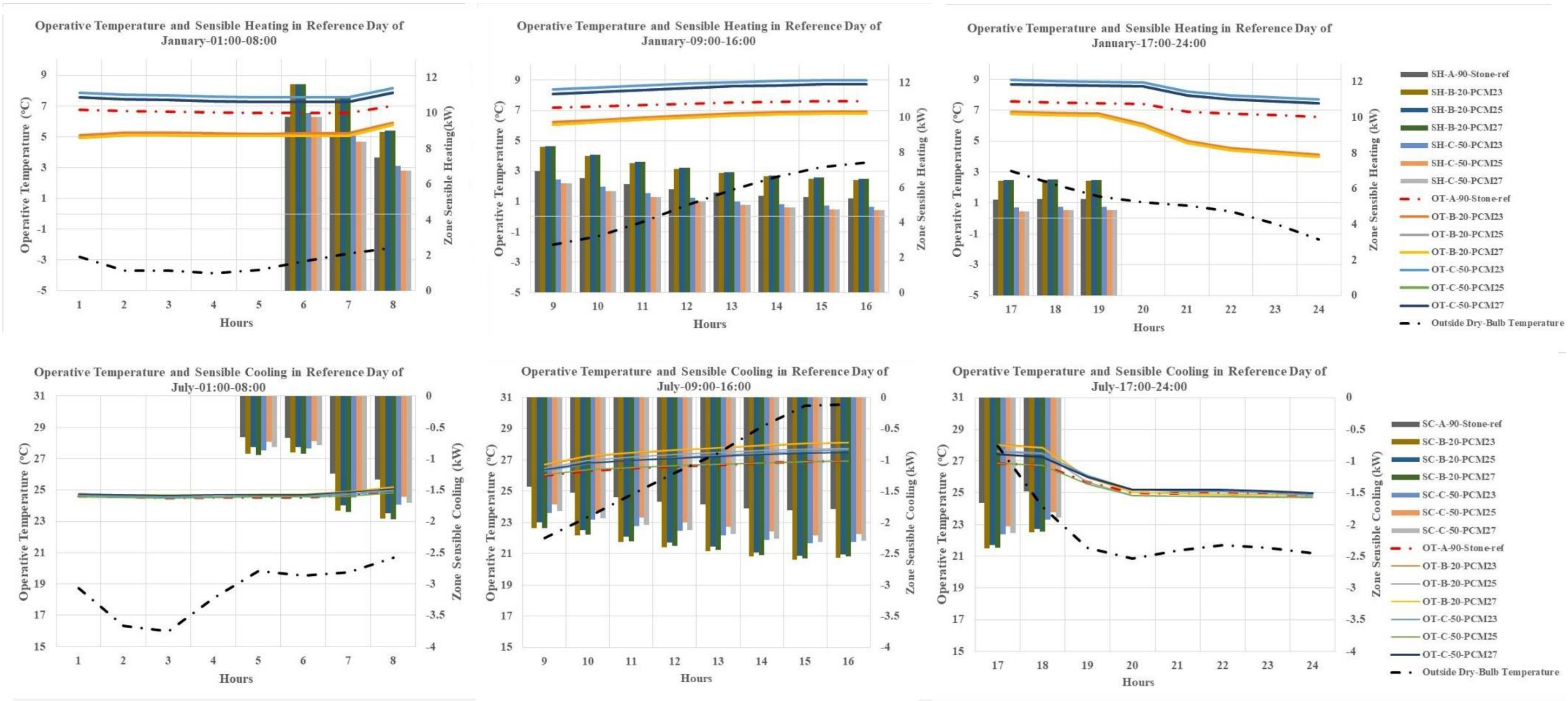

Figure 5. Daily Operative Temperature and Sensible Cooling in Reference Days of July-and January

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